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6. AUTHORS
Richard Stottler, Alexander Davis

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Stottler Henke Associates, Inc.
1660 South Amphlett Blvd., Suite 350
San Mateo, CA 94403

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Phase I Final Report

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Richard H. Stottler
Alexander Davis

Stottler Henke Associates, Inc. (SHAI)
1660 So. Amphlett Blvd., Suite 350
San Mateo, CA 94402

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A Case-Based Reasoning Approach to Operator Assessment and Operator Machine Interface Enhancement

Final Report

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0.0 Abstract

In Phase I, we investigated a case-based reasoning (CBR) approach to Operator Assessment and Operator Machine Interface Enhancement for the LAMPS SH-60R Multi Mission Helicopter Upgrade (MMHU). We developed a limited prototype case-based Operator Assessment and Operator Machine Interface Enhancement System (OA/OMIES), for the SH-60R sensor operator for a small subset of ASW situations. We developed a generic OA/OMIES architecture applicable in many other domains. The OA/OMIES tests operator knowledge through the use of tactical scenarios, derives the operator's mental model based on his performance and explanations for his actions, then adapts the operator interface based on his deficiencies revealed in the mental model. The prototype implementation provided an absolute proof by example of the feasibility of our ideas. The case-based approach offers the further benefits of automatically or semi-automatically generating the operator's mental model and of largely circumventing the difficult and time-consuming process of constructing an explicit expert mental model. Our approach could be easily extended to constitute an Intelligent Tutoring System (ITS) for the SH-60R as well.

1.0 Executive Summary

The Light Airborne Multi-Purpose System (LAMPS) includes several tactical sensors and associated signal processing and display equipment. Each has different modes, settings, and methods of operation. Especially in the case of the radar and sonar systems, essential to optimal use of the equipment is an understanding of several factors. These include the current environment and its effects on the signal propagation paths; the physics of the signal propagation; enemy tactical behavior and signal source characteristics; and the capabilities, limitations and processing algorithms of the sensors and processing systems. The sensor operator (SENSO) and Air Tactical Officer (ATO) need to make good tactical and sensor choices to accurately separate enemies from non-enemies and perform their mission well.

Unfortunately, because this is such a complicated domain (or actually several domains, since there are several mission and sensor types), the knowledge and performance of ATOs and SENSOs varies considerably. One solution would be to make the use of the equipment more automatic by automatically selecting sensor operating modes, parameters, and employment/deployment methods. However, this would detract from the flexibility and therefore the capability of the equipment in the hands of the most expert users. What is needed is a system which can assess the proficiency and knowledge of an operator in the various types of sensors and tactics and related principles of operations, assess his qualifications, and adjust the equipment appropriately.

The complex set of principles, which is required knowledge for the SENSO and ATO, is duplicated for each type of sensor, tactic and mission for which the SENSO and ATO are responsible. The sensors include radar, EMS, active and passive sonar, SAR, ISAR, and Magnetic Anomaly Detection (MAD). This complexity leads to a complex definition of operator proficiency. Simple linear labels such as Novice through Expert trivialize a very complex domain. Instead of a one-dimensional description, a very large number of dimensions is required - one for each principle or related set of principles, which implies hundreds of dimensions. A better description is to keep track of the set of principles that the SENSO or ATO has current mastery of and the set of ones on which he is weak.

Simple tests of what principles he knows and doesn't know are not sufficient. Simply questioning the operator on the principles (with multiple choice answers for example) is not sufficient, since what is most important is how the principles should be applied in a tactical scenario.

All Phase I objectives described in the Phase I Proposal were accomplished. In Phase I, we investigated a case-based reasoning approach to intelligent Operator Assessment and Operator Machine Interface Enhancement Systems (OA/OMIESs). We developed a prototype case-based OA/OMIES within the LAMPS SH-60R MMHU ASW domain. We determined the requirements, both hardware and software, for integrating the OA/OMIES with existing systems.

The ultimate Operator Assessment/OMI Enhancement System (OA/OMIES) will assess an operator's knowledge and tactical proficiency by testing him with example tactical scenarios, off-line. An example consists of a problem description, solution, and explanation or steps leading to the solution. An exercise is extracted from an example by only showing the operator the problem. He must then generate the solution himself. His solution and solution steps can be

compared to that of the exercise for grading, deficiency diagnosis, and interface alteration. The system works interactively with the operator to test his knowledge by using scenarios of sensor employment in tactical situations. These scenarios are generally presented through a tactical simulation.

In order to tailor the equipment operation to the individual operator, the system will keep a model of each operator tested using the OA/OMIES. The operator model will contain the operators' actions and decisions during different exercises, the principles, procedures, and techniques which have been tested, and those that have been mastered based on performance on exercises. The set of principles, procedures, rules, and tools referenced in the solutions of problems the operator has solved successfully represent the operator's mastered skills. Based on the pattern of his unsatisfactory performance on exercises, a set of topics and principles, or combinations of them, can be developed which form a hypothesis as to what knowledge the operator does not understand. This hypothesis is the basis for the operator model which will be used to enhance the user interface to counteract his deficiencies.

The OA/OMIES will then make use of the operator model to enhance the user interface, in a way which is customized to the particular operator and which optimizes the combined operator/sensor system performance. This enhancement may include automatically setting sensor operation or processing modes, parameters, options, etc.; priming certain help files or features for the operator; recommend certain configuration settings; starting and initializing decision aids for the operator; or making use of expert systems to configure the equipment appropriately. The enhancement can be performed in a number of ways, all of which were investigated and possibly will be implemented in parallel. Since the operator model includes the principles and skills in which the operator is weak, these are passed to the on-board enhancement system to set the OMI appropriately for the given circumstances.

The visualized sequence whereby the OMI Adaptation software will be utilized consists of 3 primary phases. The first is evaluation. In the evaluation phase, the system tests operator knowledge and builds a model of his knowledge. Much of this would occur by testing him with a tactical simulation and analyzing his responses. In the second stage, the OMI Adaptation system would present proactively, minimal tailored information on the auxiliary display during an actual mission. This mission might be either a training mission or actual combat. Finally, especially if a training mission was performed, the third phase could consist of a debriefing.

The Phase I prototype provides absolute proof of the feasibility of our ideas. The Phase I prototype implements all phases of the full-scale OA/OMIES, though on a very narrow part of the SH-60R domain. It includes both an assessment module which tests operator knowledge in scenarios running in a tactical simulation, and, an enhancement module. The assessment module assembles an operator model, consisting of what Principles the operator is weak and strong in. The assessment also performs assessment efficiently. That is, if it determines that he knows very little or very much about one part of the SH-60R domain, it marks the entire area accordingly and moves on to scenarios covering other areas.

The enhancement system uses the operator model, in the context of the current situation, to provide the appropriate enhancements. Enhancements included in the Phase I prototype

include recreation/improvement of existing sensor displays, knowledge-based advice, advisories, warnings, suggestions, explanations, and domain information (both general and tailored to the context). Section 6 lists the prototypes capabilities in more detail and Appendix A gives a series of screen dumps which illustrate a demonstration sequence which clearly shows the feasibility of our concepts.

The ultimate goal of this project is a fielded, operational system which performs off-line assessment and on-line OMI enhancement, on-board the SH-60R, for both the ATO and SO positions. This is an enormous scope which must be scaled-back and prioritized for Phase II. In Phase II, we would produce an operational prototype, ready for testing and evaluation, probably interfaced through an RS-232 port to a land-based functional cockpit mock-up. The Phase II system would handle a subset of the applicable knowledge and tasks of the SO or ATO. The ultimate system, in addition to interfacing to the actual SH-60R avionics must also interface to an SH-60R trainer, for OA/OMIES testing, off-line assessment, and for training the crew in the use of the on-line enhancements.

Future work will include both the development of applicable OMI enhancements by SHAI as well as incorporation of enhancements developed by others. The Decision Support System (DSS) is one example. Our architecture minimizes the difficulty of incorporating enhancements developed by other organizations. SHAI is qualified to develop several different types of enhancements. Which ones we develop, and which ones will be developed by others, must be decided.

2.0 Background

2.1 SH-60R

The Light Airborne Multi-Purpose System (LAMPS) includes several tactical sensors and associated signal processing and display equipment. The sensors include a dipping hydrophone, passive and active sonobuoys, EMS, radar, and Magnetic Anomaly Detection (MAD). Each has different modes, settings, and methods of operation. Especially in the case of the radar and sonar systems, essential to optimal use of the equipment is an understanding of several factors. These include the current environment and its effects on the signal propagation paths; the physics of the signal propagation; enemy tactical behavior and signal source characteristics; and the capabilities, limitations and processing algorithms of the sensors and processing systems. This is especially true in littoral environments where shallow water, near or over-flown land masses, and a large number of commercial and neutral surface and airborne contacts significantly complicates the sensor optimization problem. Because of the clutter and multipath effects in littoral environments, the sensor operator (SENSO) needs to make good sensor choices to accurately separate enemies from non-enemies.

The problem is further complicated by the tactical ramifications of the sensors. Use of active sensors often reveals the presence of the LAMPS. This loss of the surprise is serious enough in its AntiSubmarine Warfare (ASW) mission, providing warning to a submarine that it has been detected, but it is far worse in its Anti-Ship Surveillance and Targeting (ASST) mission, perhaps making the helicopter a target of attack, itself.

Unfortunately, because this is such a complicated domain (or actually several domains, since there are several sensor types), the knowledge and performance of SENSOs varies considerably. One solution would be to make the use of the equipment more automatic by automatically selecting sensor operating modes, parameters, and employment/deployment methods. However, this would detract from the flexibility and therefore the capability of the equipment in the hands of the most expert users. What is needed is a system which can assess the proficiency and knowledge of an operator in the various types of sensors and related principles of operations, assess his qualifications, and adjust the equipment appropriately. For example the system might evaluate the operator as being very expert in all aspects of radar operation and therefore allow him to configure the radar system without much help or guidance. In contrast, the system may evaluate that the same operator's knowledge is weak in the area of acoustic sound channels. In that case, the system might recommend or select hydrophone depths for the sonobuoys, while leaving the operator to select frequencies and modes.

Consider, for example, just one sensor in the SENSO's suite of possible sensors, the passive sonobuoy. Sonobuoys must be set and positioned while simultaneously considering a very large set of very diverse factors. These factors can be grouped into six categories - current mission, physics of sound, hydrophone and acoustic processing capabilities, local environment, type of targets of interest (TOI), and their likely tactics. For example, the current mission could be of several different types - localizing a detected target, screening a transiting battle group, tracking or harassing targets passing through a designated area, etc. Other mission issues involve the likely types of TOIs and their probable posture, the rules of engagement, and political constraints.

There are several principles in the physics of sound. The SENSO must have a thorough understanding of different sound propagation paths and how they are affected by the varying parameters of the local environment. He must understand how acoustic signals will be affected by their source emission and propagation to his equipment. This includes factors such as

attenuation, Doppler shifting, interference, reverberation, multi-path propagation, sound channels, effects of signal-to-noise ratios, etc..

The SENSO must have a strong understanding of the capabilities, limitations, and opportunities of his sensors and processing equipment. The sensitivity to various frequencies; processing times parameters, and options; and the required signal-to-noise ratio for detection must all be considered.

The SENSO must have a thorough knowledge of the local environment and its effects on his sensors. In littoral environments, the environment will not be horizontally homogenous as is often assumed for deep water. Temperature, salinity, and water velocity (currents) will all vary in three dimensions, as will bottom topography. Water currents and cold and warm water eddies will all be important, if present. All these factors will have a strong effect on sound propagation. The geography (such as coastline, islands, straits, other choke points, etc.), shipping lanes, fishing grounds are also important. Sources of noise which can be expected such as shipping, drilling, fishing, sea state, storms, wind, seismic activity, and biological sources should be considered during sonobuoy deployment.

The types of TOIs are important. The SENSO must have a thorough understanding of the likely sources of acoustic signatures, including propellers, engine, gears, auxiliary pumps and other equipment, cavitation, resonance, etc. He must understand when these signatures are likely to be present, how they relate to each other, and why.

Finally the SENSO must understand the likely tactics of his targets. He must understand where and how deep they will operate, what their mission and objectives are, limitations or constraints they must operate within (E.G. the need for an attack submarine to visually acquire his target, to supplement his sonar data), preferred methods of operation, and schedules or time constraints.

This complex set of principles, which is required knowledge for the SENSO, is duplicated for each type of sensor, for which the SENSO is responsible - radar, EMS, active and passive sonar, SAR, ISAR, and Magnetic Anomaly Detection (MAD). This complexity leads to a complex definition of operator proficiency. Simple linear labels such as Novice through Expert trivialize a very complex domain. Instead of a one-dimensional description, a very large number of dimensions is required - one for each principle or related set of principles, which implies hundreds of dimensions. A better description is to keep track of the set of principles that the SENSO has current mastery of and the set of ones on which he is weak.

Simple tests of what principles he knows and doesn't know are not sufficient. Simply questioning the operator on the principles (with multiple choice answers for example) is not sufficient, since what is most important is how the principles should be applied in a tactical scenario. The operator must develop a competence not only in the relevant facts and skills, but also an understanding of the concepts underlying these procedures. Learned principles need to be applied differently in different situations. For example, a typical passive acoustic depth pattern is deep - shallow - deep - shallow, which retains an ability to detect submarines operating both above and below the layer. An operator may specifically understand and apply this principle without having the more comprehensive understanding. So, for example, if a submarine can be assumed to have gone deep (perhaps because he has just out-run an active sonar tracking situation), an all deep depth setting for the sonobuoys might be more appropriate. An operator who has effectively memorized the principles as they are given in a training course may not have developed a mental model allowing him to make appropriate decisions in unanticipated situations. He might continue to use the deep - shallow - deep - shallow pattern in the latter situation, described above. This example shows that just knowing the principle is not sufficient, it must also be applied correctly and the best way to assess that application knowledge

is through scenarios which differentiate between deep and superficial understanding. If the operator assessment focuses on understanding the operator's cognitive representations of the domain and concepts rather than procedures only, the operator interface can be adapted to him more effectively. Of course the example above is greatly simplified, but it presents the problems facing operator assessment and OMI enhancement in decision-oriented domains. What is needed is a way to automatically assess the knowledge of operators in this complex domain, and automatically reconfigure the sensor equipment for different levels of expertise in different areas

Consider the simplified example of a SENSO who does not understand the surface duct phenomenon, and simply assumes the detection range of radar surface-to-surface is a constant range, regardless of environmental conditions. An automatic assessment system which concludes that the SENSO does not understand the surface duct phenomenon, may adapt the OMI to make automatic use of the EMS when a surface duct is present and when the suspected location of the enemy is outside the normal detection range but within the surface duct range. The system may have determined this SENSO's weakness by his performance on several scenarios, where his use of sensors violated the recommendations of experts for the same situation and those scenarios involved the use of the surface ducting phenomenon.

2.2 Artificial Intelligence Methodologies

Case-Based Reasoning

Many studies have been performed on utilizing prior experience, or analogical reasoning, in various domains and on representing prior situational knowledge. Humans reason about a given situation based on knowledge about that situation and associations to previous experiences. This same reasoning process applies to assessment - how well a sensor operator will perform in a given situation is likely to be similar to his performance in similar situations.

Case-Based Reasoning (CBR) is the field of AI which deals with the method of solving a current problem by retrieving the solution to a previous similar problem and altering that solution to meet the current needs. CBR is a knowledge representation and control methodology based upon previous experiences and patterns of previous experiences. These previous experiences, or "cases" of domain-specific knowledge and action, are used in comparison with new situations or problems. These past methods of solution provide expertise for use in new situations or problems. From our previous ITS experience, we believe that the general problem of assessing operators is well suited for the application of such a case-based reasoning method.

CBR systems offer enormous benefits compared to standard AI approaches. The knowledge elicitation bottleneck is largely circumvented. Cases can be automatically acquired directly from domain experts. Rules, on the other hand, almost always require the intervention of a knowledge engineer. Instead of having to elicit all of the knowledge required to derive a solution from scratch, only the knowledge required to represent a solution is needed. So knowledge elicitation is largely avoided with CBR and may be COMPLETELY automated depending on the type of application and the expert. This makes CBR especially appealing for an operator assessment and OMI enhancement framework that will potentially be applied to multiple domains, because it reduces the knowledge engineering time requirement.

Conventional knowledge base technology dictates a single, fixed problem solving methodology. With CBR, each case, in the extreme, can represent a different methodology. This is important for complex domains where different problems or situations, although sharing the same fundamental concepts, may require different solution strategies.

Stottler Henke Associates, Inc. (SHAI) has performed several projects which emphasized operator assessment based on CBR. Many included simulations, both existing and new. One project dealt with assessing sonar technicians. Our extensive experience with assessment of mental models for use by ITSs and our experience with automated problem-solving can be applied to this project.

We have developed a methodology that aids human experts in structuring their experiences for application to new problems. This methodology has proven successful in a variety of domains for guiding analysts in the systematic application of case-based judgments to new situations. Our approach to the development of a case-based intelligent assessment and OMI tailoring system will be grounded in this accomplishment. We will extend this method for identifying and formalizing case experience into a system for documenting, codifying, and referencing completed case analyses. We will use our experience in decision-aid design in the construction of a general intelligent assessment and OMI enhancement system built on this case-based knowledge foundation.

Knowledge Elicitation

In developing a Case-Based Reasoning (CBR) system for intelligent assessment and OMI enhancement, we first query the domain experts for cases (examples). An active querying strategy helps us learn more about tacit knowledge, such as rapid situation assessment abilities. Without direct probing, domain experts may be unable to provide explicit motivations for their judgments. Often they gain insights that are new, even to themselves, about how they formed those judgments after responding to the questions. For these reasons, we have a great deal of confidence in our ability to elicit the knowledge and perceptual and reasoning strategies that are necessary components of a model that will be effective for making high level decisions.

Our primary interviewing technique is case-based, dealing with actual incidents that the subject matter experts recall from experience. By using this approach, the experts' actual mental representations of their domain are elicited. All of these data are analyzed and abstracted to formulate a hierarchical structure representing the relationships between the various domain components.

Each case elicited will consist of three main parts: the problem, the solution, and the process of deriving the solution, along with explanations of each step of that process. The problem part is an explanation of the problem to be solved and will be partly graphical in nature to describe the tactical situation. The solution will consist of the proper SENSO actions to take and may take the form of a simple set of sensor settings, or be more complex such as an involved sequence of correct actions to take in the tactical scenario. The solution process is the most complicated part of all. It consists of the steps required to solve the problem. With each step is a reference to the general principles or methods used in that step. Each reference points to a principle or method in the body of knowledge that the operator should know. Any principle could be referenced many times in different cases but that principle would only be represented once in the body of knowledge. A detailed explanation of the referenced principles and problem solving methods could be requested from instructors, thus automatically extending the OA/OMIES. The cases force the expert operators to include only and all information required for problem solving. A reasonable organization is mapped onto unorganized experts.

Knowledge Representation

In order to automate operator assessment and the resulting OMI enhancement, we first established a representation in the computer of the knowledge required. Stottler Henke Associates, Inc. (SHAI) has extensive experience in selecting AI knowledge representations appropriate for a

particular domain. In fact, each of our implementations begins with selection of the knowledge representation and definition of the knowledge (see Related Work). An appropriate knowledge representation is one that naturally and completely captures desired knowledge in the domain and that can be successfully and easily manipulated to meet the needs of the application. Using these selection criteria and the knowledge we have gained from previous projects, we decided to use objects to represent the cases of tactical scenarios for sensor employment which will be used for testing and enhancement a well. We have also found an object hierarchy useful for representing the complex set of principles required for optimal operation of the sensor suite. The operator's mental model generally is represented as an object which references principles objects and performance objects. These performance objects are created each time the student is tested on a scenario. They record his actions and explanations and reference the case (scenario) on which he was tested. Additional components that must be represented are the sensors themselves, along with configuration options, the signal processing equipment along with its configuration options, the OMI and its components, the SENSOs tasks and missions, the environment, the current tactical situation, and any automated tools that the OA/OMIES can make use of to enhance the OMI..

Object Oriented Programming (OOP) is a methodology for both representation and programming. Using OOP techniques, one can define different types of objects and specialized program methods that manipulate them. An object consists of slots which specify the object's characteristics or subcomponents. Slot values may be of several different types: pointers to other tasks, numerical values, Boolean values, lists, or text strings. Objects can be connected together into a semantic network, where the nodes of the network are the objects and the arcs of the network are the relationships between the objects. OOP facilitates automated enhancement, where various object representations of OMI components configure themselves. Each object used in the enhancement process has an associated enhance method and, in effect, enhances itself, triggering the enhancement of its subcomponents or related components. The concept of intelligent entities allows complex enhancement algorithms to be built from very simple, particular ones. The developer, or even user, also has the capability to mix and match enhancement methods at the different levels of the enhancement hierarchy and at different components at the same level.

Object representations do not preclude the use of other representations, and in fact, integrate well with them. Other representations which are useful, in addition to cases and objects, are rules, expert system technology, Model Based Reasoning, and Fuzzy Logic.

Interactive Multimedia

Interactive multimedia is used to both present the examples for testing and to enhance the OMI, when required. SHAI has experience in the following media:

- Interactive Simulations
- Interactive 3 Dimensional graphics
- Interactive Photos
- Audio
- Interactive Animations
- Video
- Hypertext
- Virtual Reality

Interactive simulations are especially useful as exercises for assessing operator use of sensor systems in tactical situations. For example, in the Aegis ship survivability domain, we

used an intelligent tactical simulation to test TAO knowledge or relevant principles. The operator could control own ship sensor configuration and sensor and weapon system In our previous simulations work, we have developed tools and techniques for the rapid development of object-oriented simulations.

Another technique, related to simulations is interactive animations. In the example above, instead of just printing the results of the simulation, the current sensor contacts and tracks are animated. Seeing the incoming missile either destroy the ship or be destroyed by the intercepting missile makes the example much more vivid and therefore more likely to be remembered. SHAI has already developed a general three-dimensional animation capability.

Interactive 3 dimensional graphics is another important tool. In many applications, both tactical and equipment-oriented, three dimensional visualization is required. The view can be rotated by the operators to gain a clearer understanding. Other computer generated graphics such as bar charts, pie charts, bitmap files, line graphs, and plots can be supported. SHAI has already developed an interactive three-dimensional graphics capability.

An extension of the interactive simulations, animations and 3 dimensional graphics is virtual reality technology. Through the use of head mounted displays or goggles; hand, finger, and body tracking; and three-dimensional sound, an operator can achieve a more realistic, immersive experience in the tactical simulation. SHAI is currently involved in two virtual reality projects.

Video can be especially helpful in the descriptive section of a scenario. Videos can be made interactive by allowing user controlled slow motion, freeze frame, rewind, fast-forward, and branching. Branching is allowed at certain points in the video by giving the user a choice about which video among a set of choices to see. SHAI has previously integrated video clips into our software.

Interactive photos also lend vividness to presentations and examples. A photo is interactive if can be zoomed or panned. Certain regions or annotations may be mouse-sensitive to allow further information to be presented such as hypertext or other photos. SHAI has implemented a prototype zoom capability in our targeting project (see Related Work).

Hypertext is mouseable text with further information available on mouseable words or topics. This further information may also be hypertext or some other kind of media. SHAI has developed several systems utilizing hypertext.

Another possible media is audio. Audio can be sound recording to add realism to an example or might be recorded or generated voice which describes the tactical situation or asks questions as to the rationale for operator actions in it. Audio can be made interactive in the same ways as video. SHAI has previously utilized computer generated speech for a project to help nonvocal quadriplegics communicate.

3.0 Phase I Objectives/Tasks

Section 3.1 gives the original Phase I technical objectives listed in the original Phase I proposal (all of which were accomplished) and Section 3.2 describes the tasks of this phase I effort.

3.1 Phase I Objectives

All Phase I objectives described in the Phase I Proposal were accomplished and are reproduced below. In Phase I, we investigated a case-based reasoning approach to intelligent Operator Assessment and Operator Machine Interface Enhancement Systems (OA/OMIESs). We developed a prototype case-based OA/OMIES within the LAMPS SH-60R MMHU ASW domain. We determined the requirements, both hardware and software, for integrating the OA/OMIES with existing systems. Specifically, there were five Phase I objectives listed in the proposal and approved at the kick-off meeting which are listed below. The Phase tasks and results are further described in more detail below in Sections 3.2 and 4.0.

1. Identified LAMPS SH-60R MMHU Assessment and OMI Enhancement Requirements: Working closely with the Navy, we identified a specific subset of the MMHU domain for which operator assessment and OMI enhancement must consider the cognitive abilities of the operator.

2. Developed Strategies for Mental Model Assessment: Through intelligent indexing of scenarios and other techniques, we developed general analytical routines for assessing an operator's mental model.

3. Developed Strategies for OMI Enhancement. Given an accurate mental model of the operator, we determined how the OMI can and should be altered. One method was to use CBR applied to expert scenarios of sensor employment. Another was to develop rules, methods, or algorithms based on the set of principles in which the operator is weak. Various metrics were investigated and developed.

4. Case-Based Representation and Reasoning Architecture: We produced a generic architecture for the case-based OA/OMIES. The benefits of CBR for both automated assessment and intelligent, operator-tailored adaptation of the OMI were demonstrated through this system.

5. Prototype Development: We developed a proof-of-concept prototype on a PC, based on the system architecture. The prototype demonstrated important CBR functionality both as a general assessment and OMI enhancement system and as an OA/OMIES implementation within a subset of the LAMPS SH-60R MMHU domain. This aided us in the prediction of computational requirements of the final system.

3.2 Phase I Tasks

An eight task approach was proposed for accomplishing the Phase I research objectives. The tasks were to:

1. Select the subset of the LAMPS SH-60R domain to focus the study
2. Define the preliminary case structure for the elicitation procedure

3. Conduct knowledge elicitation
4. Design the case base structure and retrieval methods
5. Investigate Techniques for OMI enhancement
6. Investigate the integration requirements
7. Implement OA/OMIES prototype
8. Prepare the Phase II OA/OMIES design and final report

Task Descriptions

1. Select the subset of the LAMPS SH-60R domain to focus the study: Working in conjunction with Navy representatives, we selected a representative subset of the LAMPS SH-60R domain for our feasibility study. We chose to concentrate on the sensor operator and, more specifically for the prototype, on ASW situations. We did include tasks normally associated with the ATO as well. The results are given in Section 4.0.

2. Define Preliminary Case Structure: We determined an appropriate representation for cases in the domain. The cases consisted of attributes for describing the problem-solving principles and methods as well as their explanations. We also examined potential similarity metrics and retrieval methods.

3. Conduct knowledge elicitation to develop the domain model: Based on the research into the general qualities of mental models, SHAI elicited knowledge from experts in the SH-60 ASW mission. We applied a cognitive task analysis approach, where the critical decisions were identified and the factors and issues which must be considered were elicited. We made strong use the knowledge acquisition method - Method of Cases, where experts ran through examples from their experience.

Our thesis was that assessment and OMI enhancement strategies would be primarily case-based, because the complexity of the required operator mental. Domain experts were interviewed individually and presented with problems to determine their mental model by recording their situational performance both in previous experiences and new scenarios. The experts' knowledge was used to develop a quality representation of the trial domain, by which operators' mental models will be measured. Typically Case-Based Reasoning (CBR) techniques can be used effectively for knowledge acquisition in case-based applications, and this was effective for this domain as well. Thus, a CBR knowledge elicitation component will likely be employed in the Phase II OA/OMIES based on the findings in the Phase I elicitation.

4. Design the structure for the case base and retrieval methods: We produced a generic architecture for the case-based OA/OMIES which is described in Section 5.0. The benefits of a case-based approach for automated knowledge acquisition, intelligent assessment, and operator-responsive OMI enhancement were demonstrated through this system. The case structure was capable of representing an example (scenario) which included the problem (tactical situation), its solution (sensor system configurations and actions) and an explanation of the solution which referenced general principles and methods. An object-oriented approach was used to represent a case. We used object structures to provide a framework for knowledge representation and program control. As the case structure was defined, a retrieval method was outlined for the system. It is the intelligent retrieval which served as the primary driver of the operator assessment, followed by an analysis of the operators performance.

5. Investigate Techniques for OMI enhancement

SHAI investigated techniques to use the operator model to enhance the user interface, in a way which is customized to the particular operator and which optimizes the combined operator/sensor system performance. This enhancement investigation included both the types of alterations to be made as well as how those alterations can be accomplished automatically. The types of alteration included automatically setting sensor operation or processing modes, parameters, options, etc.; priming certain help files or features for the operator; recommending certain configuration settings; starting and initializing decision aids for the operator; or making use of expert systems to configure the equipment appropriately. We investigated a number of enhancements, including use of rule-based or other knowledge based systems; use of the cases acquired from experts; and other technologies.

6. Investigate the integration requirements: We worked with the Navy to determine the hardware and software requirements for integrating the OA/OMIES with the new hardware and software systems being developed for the SH-60R and for placing the OA/OMIES onboard to support OMI enhancement.

7. Implement OA/OMIES prototype: We developed a prototype OA/OMIES for the LAMPS SH-60R MMHU, to provide an architecture for evaluating the feasibility of an case-based OA/OMIES. This prototype incorporated the strategies developed earlier for intelligent operator mental model assessment and OMI enhancement. It was designed for easy application to new domains. This prototype provided a sample of the "look and feel" of the system and contained representative CBR functionality that operated on the chosen subset of the LAMPS SH-60R domain (ASW Sensor Operations). It was used to demonstrate a specific application of the use of examples in assessment and OMI enhancement. It also demonstrated the ability of the system to automatically retrieve similar examples, and to modify sensor equipment OMIs to meet current operator needs. While initial evaluation of the prototype was be carried out in Phase I, its primary use will be in Phase II for more comprehensive testing of the assessment and OMI enhancement strategies and possible exploration of other domains. It is described in more detail in Section 6.

8. Prepare the Phase II OA/OMIES design and final report: This final report describes the development and architecture of both the general and the specific case structures and retrieval methods and includes the Phase II design, in Section 5.0. This design includes the architecture for all modules. The evaluation of the prototype in its trial domain is presented. A future research section outlines the requirements needed to develop the full-scale, general intelligent OA/OMIES, for use on-board the SH-60R.

4.0 Phase I Accomplishments/Results

This project really got underway at the kick-off meeting which was held March 18th. It was decided there to tend to concentrate on the sensor operator, since that position appeared to be fluctuating less. We did review several documents (SH-60F NWP, OEC for SH-60R, LAMPS MK III Block II Upgrade Design Description Document, and the HEDAD-O). A choice within the two broad domains of the MMR and acoustic systems appeared to be the most promising, since these appear to require the most operator knowledge, be the most difficult set of tasks, and relate to the aircraft's two primary missions. Two possible choices, because SHAI already had some experience in these areas, were to concentrate on passive acoustic detection and classification or passive sonobuoy placement decisions. We did end up choosing acoustic systems on which to concentrate. More specifically, the subset chosen during the recent visit was the union of domains of two operator-machine interface problems, each of which was taken from a 'DSS wish list' composed by VX-1. One problem was the multitude of processor mode combinations during passive acoustic search, for which our system should provide sensor settings recommendations to an inexpert or overwhelmed operator. The other problem was the inability to associate contacts on multiple sensor types, which could be solved by having our system provide alerts to contact information not being viewed by the operator, when appropriate. These two problems guided our development of a knowledge base and interface enhancement prototype.

On 28 May we met with Russ Hallauer to discuss the SH-60R domain, specifically in the context of the year 2005 scenarios. This discussion resulted in broad tactical and operational knowledge, as well as contacts for further investigation of the platform's usage in detail. The following day we visited VX-1 at Patuxent River, where we established expert contacts and tentative plans to observe their development of the next scenario, and discuss with them low-level considerations of the original six scenarios.

During the week of 11 August we did visit VX-1 at Patuxent River and met with several expert contacts. A working group meeting served to better define the scope and target functionality of the Phase I effort, and individual meetings with experts have given us a good deal of knowledge of the relevant domain. Our discussions also revealed the applicability of various interface adaptation techniques, as suggested and evaluated by expert aircrew. We obtained several documents detailing the tactical and technical operation of the SH-60R and its various sensor and weapon systems, and we visited the Replacement Air Groups at North Island in order to observe training on the SH-60B and SH-60F platforms. The knowledge gathered during this visit was sufficient for us to complete a more detailed design and begin definition and implementation of the system's computational architecture. A preliminary design of the system is given in Section 5.0. Further research and a visit to North Island, allowed us to flesh out our operational knowledge base, as well as resolve remaining low-level implementation and interface details.

On-board Fielding Issues

The OA/OMIES will be highly feasible to field on-board the SH-60R for several reasons. Using the laptop concept saves space, weight and power. Typical laptops with 12 " screens weigh about 7 pounds (extra hardening may add some small amount of weight), take up less than a tenth of a cubic foot when closed (8.5" x 11" x 1.75"), have small operational dimensions (8.5" x 11" x 10", open), and use little power (20 Watts). The computational power and space requirements of our approach our modest, allowing the use of existing Pentium laptops, which easily provide the needed computational power. The power interface would tend to be a simple low-power DC connection, as required by the laptop manufacturer. Worse-case a small, inexpensive transformer would be required to change the on-board voltage for the laptop. The data interface would be via a standard RS-232 connection. The bandwidth requirements of the connection are very low, with the possible exception of sensor images. These would only be needed if the enhancement system included classification aids, running on-board the laptop.

Furthermore, the OA/OMIES can be implemented in a highly efficient and modularized manner. We estimate less than 40,000 software lines of code (SLOC), based on previous implementations that we have performed at similar levels of effort. This SLOC will be divided up into several very separate modules for easier implementation and testing. First, the assessment and enhancement modules are so separate that they will be running on different processors and at different times. Second, the domain knowledge is separate from the scenario and case knowledge which is separate from the software which makes use of it. As described in Section 5.2 the assessment and enhancement modules are also divided into smaller, very separate components. Finally, the most critical software, that actually runs on-board, does not include the assessment system and is mostly made up of very separate enhancement codes, as described below and in Section 5.2.

5.0 Phase II OA/OMIES

5.1 System Functionality

General

The Operator Assessment/OMI Enhancement System (OA/OMIES) will assess an operator's knowledge and tactical proficiency by testing him with example tactical scenarios, off-line. An example consists of a problem description, solution, and explanation or steps leading to the solution. An exercise is extracted from an example by only showing the operator the problem. He must then generate the solution himself. His solution and solution steps can be compared to that of the exercise for grading, deficiency diagnosis, and interface alteration.

The system works interactively with the operator to test his knowledge by using scenarios of sensor employment in tactical situations. These scenarios are generally presented through a tactical simulation. But, they may also be presented by simply explaining the situation to the student and getting back from him how he would operate his sensor equipment in that situation. This approach was taken in a project to assess Sonar Technicians (STs) in their ability to configure their processing equipment and analyze LOFARGRAMS. The tactical situation was presented to the ST, he decided how to configure the equipment, and the corresponding LOFARGRAM was displayed. This often created additional opportunities for processing configuration choices.

In order to tailor the equipment operation to the individual operator, we will keep a model of each operator tested using the OA/OMIES. The operator model will contain the operators' actions and decisions during different exercises, the principles, procedures, and techniques which have been tested, and those that have been mastered based on performance on exercises. The set of principles, procedures, rules, and tools referenced in the solutions of problems the operator has solved successfully represent the operator's mastered skills. Based on the pattern of his unsatisfactory performance on exercises, a set of topics and principles, or combinations of them, can be developed which form a hypothesis as to what knowledge the operator does not understand. This hypothesis is the basis for the operator model which will be used to enhance the user interface to counteract his deficiencies. The operator model can also be referenced by a supervisor or Intelligent Tutoring System (ITS) to monitor the operator's abilities and weaknesses and attempt to remediate them. If an ITS is used, cases which have been stored for testing can be used to help remediate him. The operator model will be high fidelity and reflect the skills, knowledge, and error-rate of the operator. The model will evolve in size and complexity as the skills and knowledge of the operator increase.

The OA/OMIES will then make use of the operator model to enhance the user interface, in a way which is customized to the particular operator and which optimizes the combined operator/sensor system performance. This enhancement may include automatically setting sensor operation or processing modes, parameters, options, etc.; priming certain help files or features for the operator; recommend certain configuration settings; starting and initializing decision aids for the operator; or making use of expert systems to configure the equipment appropriately. The enhancement can be performed in a number of ways, all of which were investigated and possibly will be implemented in parallel. Since the operator model includes the principles and skills in which the operator is weak, these are passed to the on-board enhancement system to set the OMI appropriately for the given circumstances. For example, if the operator is weak in the concept of the shallow sound layer for acoustic signals, then a rule might set the hydrophone depths for the sonobuoys, automatically, based on the current layer depth and thickness, or display the appropriate recommendations. In a more complex situation, the rule

might call an entire expert system, to calculate and set sensor parameters. The list of sensor settings associated with each principle could also be generated automatically from the cases in the system, since each action (such as setting a sensor parameter) has an attached description which includes references to principles.

Another opportunity exists for adapting the interface. Since the cases include optimum sensor settings, according to an expert, they can be used to set the sensor equipment configuration. Cases which are similar to the current tactical situation can be retrieved. In those cases, sensor configuration settings that required use of principles the operator is weak in, could be used as a basis to set the sensor configuration in the current situation. Multiple similar cases could be retrieved, if the case-base is sufficiently dense, to confirm the correctness of these settings. For example, the situation may be to relocate a nuclear submarine that has escaped an active tracking attempt. A similar case is retrieved from the case-base of expert entered scenarios. This similar past scenario may involve trying to reacquire a nuclear submarine after an unsuccessful attack, in similar acoustic conditions. The expert, in that case, has set his sonobuoys on the deep setting with an explanation that references the principle that nuclear submarines typically run fast and deep when detected. Say, for this example, that when the system examines the operator's mental model it finds that the student is either weak in his understanding of nuclear submarine tactics, or this principle in particular. It then uses the expert's deep sonobuoy setting as a basis for determining that the deep setting is also applicable in this situation and since the operator is deemed weak in this area, the deep setting is recommended for the sonobuoys.

Another way the cases can be used is to scan the cases similar to the current situation, for references to principles that the operator is weak in. Any sensor configuration settings which reference those principles should be set automatically to defaults as calculated by rules, expert or knowledge-based systems, or comparison to similar cases.

A case-based OA/OMIES can monitor the operator's actions in simulations and analyze them with respect to the different aspects of a domain. For example, during a simulation, a sensor operator might configure the acoustic processing system to have very long integration time (perhaps 8 minutes) in a situation when it is not appropriate (such as attempting to track a fast-moving target), but perform the procedure of setting the integration time correctly nonetheless. The operator's performance needs to be analyzed to determine the correspondence between the different components of his mental model and those of the domain. While the steps involved in the integration time setting procedure may be understood, the tactical decision of when to do so needs to be an identified weakness. An OA/OMIES can easily identify this deficiency by testing the student on passive acoustic scenarios. During actual OMI configuration, based on this weakness, the OMI may be configured such that the integration time is set at a more appropriate default, such as 1 to 2 minutes.

Overview

After reviewing the HEDAD-O document, with more concentration on the Sensor Operator, it appeared that direct manipulation of the SH-60 interface may be inadvisable. Starting from the ideas presented to SHAI at the kick-off meeting we are proposing the following concept: The sensor operator is provided an additional display, ostensibly for the display of help files. On-board the Space Shuttle, where similar integration, safety, and mission critical concerns exist, they often use laptop computers for similar functions as those described here. That might be a possibility, though not a requirement for our approach, for the SH-60R. This additional display would be under the control of the SHAI OMI Adaptation software. It could monitor the operator actions and the outputs and states of various systems through the same

interface as the DSS or its own RS-232. The Adaptation software roughly needs the same set of data that is displayed to the operator, with the possible exception of sensor images, which would only be needed if there will be automatic classification aids. I believe an important and powerful display concept is to minimize the spontaneous presentation of information on this display for 3 reasons. 1) This additional display is inherently auxiliary in nature; it is not the primary interface to the operator. 2) As such, it will be a distraction from the primary displays and should, therefore, be used sparingly, only when positive proof exists that there is a good reason to. And 3) having the display primarily blank, only showing information when the system knows that the operator needs it, will teach the operators that when something is displayed, he needs to pay attention to it, that it is addressing a relevant knowledge deficit that they have. This will keep the operators from learning to ignore these spontaneous helps and advice.

The visualized sequence whereby the OMI Adaptation software will be utilized consists of 3 primary phases. The first is evaluation. In the evaluation phase, the system tests operator knowledge and builds a model of his knowledge. Much of this would occur by testing him with a tactical simulation and analyzing his responses. The amount of detailed knowledge required to operate the SH-60R may preclude testing all knowledge through scenarios. Some device operation specific details may need to be tested though a multimedia question and answer format. In one project we are performing, operator stations in a CIC are rendered in a virtual environment. Something similar could be done to efficiently and accurately question the operator about device operation knowledge. After evaluation, the identified deficiencies could be fed to a training system which could try to remediate them. Reevaluation should then occur to update the operator's knowledge model. In the second stage, the OMI Adaptation system would present proactively, minimal tailored information on the auxiliary display during an actual mission. This mission might be either a training mission or actual combat. Finally, especially if a training mission was performed, the third phase could consist of a debriefing.

SH-60R OMI Adaptation and Display Concepts

There are several interface adaptations that could be made on the auxiliary display. One is that Help information appears when the operator is in either a situation he is known to be weak in or accessing equipment or modes which he is deficient in. Usually this is a blank screen - it ONLY displays information when the system knows he needs it. Therefore it could be very powerful and not distracting. If text appears, it is probably something he doesn't know. Of course he could always request help when the screen is blank, or navigate around a hypertext help system.

Another form of adaptation is to make suggestions as in an Expert System, SO's Associate concept. Again, the system would filter the suggestions so that the expert system only provide information when the operator is known to be weak in the area (or he explicitly asks for it). This advice might include which displays are appropriate for which tactical situations, since there are several choices and it has a huge effect on situation awareness.

An interesting specialization of this concept is classification aids (if he's weak in one of those areas). Possible ideas are an ISAR images case base, ISAR classification principles/procedures, advice on acoustic analysis such as which processing and display options to use, suggested buoy/dipper patterns/types/configurations, etc.

Another type of adaptation involves recreation of an existing display (that would typically appear on his primary display as described by the HEDAD-O). Adaptations include highlighting something that the operator has shown he frequently misses; indicating that this is the display that the operator should be looking at (when he's weak at deciding or something important has shown up); changing the display for operator identified weaknesses such as allowing for differences in cognitive capacities (e.g. degree of complexity); and making it better for a particular operator - e.g. overcoming sensor envelope display limitations and more complex operator-tailored decluttering.

The system could, as mentioned earlier, provide off-line training. This could take the form of a unique form of just-in-time training, which is both mission and operator specific. The training system could exercise him in areas both that he's weak in and that are required for the mission. It also allows the system to test him on the important (for that mission) issues one last time.

5.2 Design

5.2.1 Summary

The Operator Assessment and Operator Machine Interface Enhancement System (OA/OMIES) is composed of two major subsystems: the assessment module, which determines the areas of the operator's expertise and generates a mental model for that operator, and the enhancement module, which makes use of the mental model to enhance the operator's interaction with the SH-60R. A core knowledge base underlies both modules, composed of a hierarchy of principles that capture the expertise crucial to proficient crewman performance in all areas of the SH-60R operational domain. This knowledge base is associated with a case base of mission scenarios, describing in each case the expertise necessary to proper understanding of and performance in that scenario. The case base forms a set of simulation scenarios to be used in operator assessment, and also allows for case-based retrieval of scenarios in support of real-time machine interface enhancement. The overall design is shown in Figure 1.

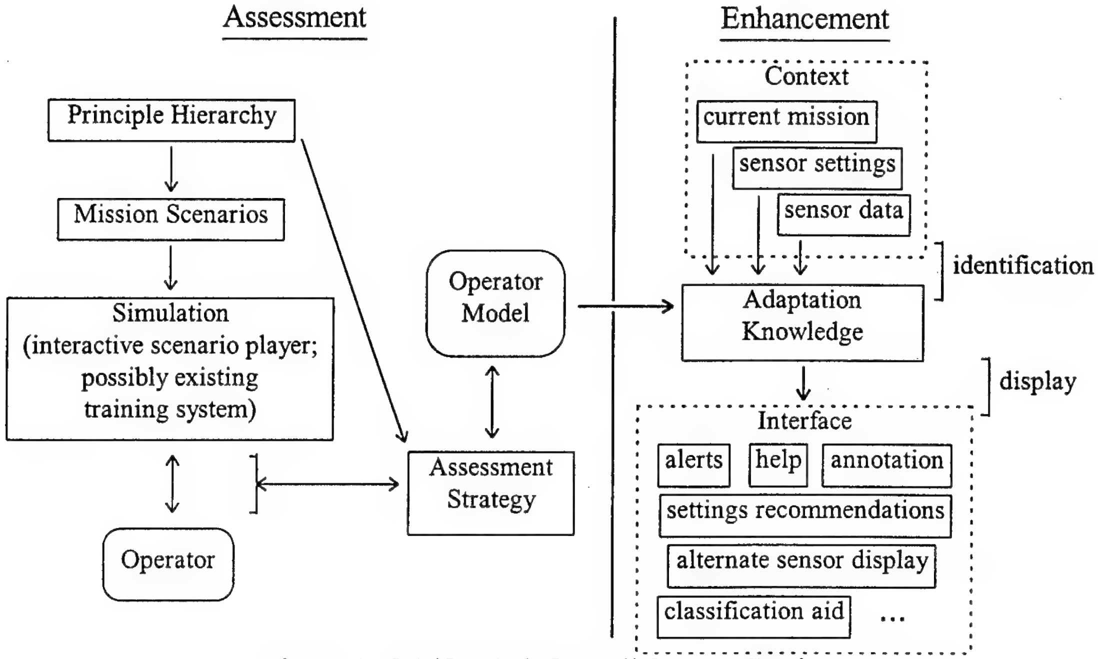

Figure 1. OA/OMIES Overall System Design

Knowledge Base

The knowledge base used in the OA/OMIES is a hierarchical breakdown of interrelated principles capturing expertise in SH-60R operations in the ASW and ASST domains. Table 1 is a partial list of the highest levels of the hierarchy.

Table 1. High-level Principle Hierarchy

- physics
    - acoustic
        - ocean layering
        - Doppler
        - harmonics
        - littoral effects
    - electromagnetic
        - ducting
- equipment (repeated for all sensors, weapons, consoles)
    - proper operation
        - configuration
        - capabilities
        - limitations
        - abnormal operations
    - interpretation of data
        - classification
- mission (repeated for ASW & ASST)
    - situational awareness
    - tactics
        - execution of mission
            - search
            - localization
            - tracking
            - attack
        - covertness
    - team coordination
        - division of labor
    - external communications
        - ownship coordination
    - scene of action command
- enemy
    - platforms
        - capabilities
        - signatures
    - tactics

The lower levels of the complete hierarchy are composed of general and specific principles which include the operational knowledge necessary to determine the appropriate action for a crewman to take in a particular set of circumstances. For instance, in the initial implementation of the search phase of an ASW mission, the mission principle of maintaining covertness suggests the use of acoustic buoys, principles of sensor limitations and presumed capabilities of the submarine suggest a particular sonobuoy placement pattern and depth settings to optimize detection, principles of situational awareness and console operation suggest monitoring of certain sensors on certain displays, and principles of sensor data interpretation suggest the outcome of localization and classification. As events unfold, various principles come into play suggesting the appropriate conclusions and reactions resulting from new data and circumstances.

The principle hierarchy, and associated knowledge about proper application of principles to scenarios, provides a facility for detecting at any time in a mission a correct action (e.g., evasive maneuvers) and/or determining a correct conclusion (e.g., target submarine is deeper than expected). The goal of the OA/OMIES is to detect situations in which a particular operator might be lacking relevant expertise, and in those situations enhance the machine interface to aid performance of the most appropriate action or inform the operator of an appropriate assumption.

Assessment

The knowledge base described above can be considered the expert model to which operators are compared, although the case-based approach used in the OA/OMIES circumvents the need for explicit construction of an expert model. The purpose of the assessment module of the OA/OMIES is to generate a mental model for each operator, formed as an annotation of the principle hierarchy describing that crewman's deficiencies in understanding. In general the system will determine whether or not each operator has an understanding of each principle, from the general (underwater sound propagation in littoral environments) to the specific (how to configure a particular weapon fire control solution). Because this determination is performed through the simulation of scenarios, deficiencies are identified in an operational sense, as opposed to explicit knowledge tests which detect only declarative ("textbook") knowledge. Cognitive psychology has produced extensive evidence that a person may have extensive capture of the latter, and yet be unable to apply that knowledge effectively, as with the former. While the OA/OMIES could be used for conventional instruction in training environments or in flight debriefing, it is essential that interface enhancement be sensitive to an operator's ability to employ operational knowledge in realistic situations.

Case Base

Assessment of an operator's expertise is performed automatically by observation of the performance of the operator in mission simulations. For this purpose the OA/OMIES draws upon a case base of mission situations, each case representing a particular set of possible circumstances. The cases are associated with sets of principles which comprise the expertise necessary to perform correctly in those circumstances, and they themselves represent the correct actions that those principles indicate. In contrast to an actual expert system which is capable of

conducting warfare, the OA/OMIES employs cases as templates in order to detect whether an operator is conducting the correct course of action. This application of case-based reasoning makes the task of the OA/OMIES tractable, circumventing the need to implement an entire automated operator, while still providing applicable and useful aid to the operator.

Retrieving a case that is suitably similar to the current situation in a simulation, or in a real mission, will reveal the set of principles pertaining to that situation and the set of actions that are appropriate. Cases are represented in a constraint-based fashion, with various levels of generality. One case could represent littoral ASW in general, suggesting the applicability of principles of shallow-water physics, constraints of enemy maneuvering, appropriate search techniques, etc. Another case could represent a particular localization situation in littoral ASW, suggesting also sonobuoy placement pattern and depth settings, etc.

The utility of this case-based approach is enhanced by the ability of experts to expand the case base by simulating further situations, and then entering them as cases associated with certain principles; that case would then be usable immediately in the OA/OMIES. In this sense, the OA/OMIES forms the larger part of an authorable intelligent tutoring system. As the case base expands to include specific cases for a variety of situations, its enhancement of the SH-60R interface will become more specific and detailed. Because the case base associates the principle hierarchy with certain mission situations, the two collectively form the underlying contextual knowledge base of the OA/OMIES.

Scenarios

Cases are distinct in the OA/OMIES from assessment scenarios, which are sets of initial conditions of simulations. As in a conventional training simulation (which could be used for this purpose), each scenario presents to the operator a set of precise circumstances, and a current mission objective, in which to act. The interface to the simulation is a virtual recreation of the operator's station. As the operator attempts to execute the mission and events unfold, the OA/OMIES retrieves cases from the case base which match the particular conditions of that moment in the scenario. The resulting cases will determine the appropriate response to those situations, and when the operator differs from these actions, the OA/OMIES will assume a deficiency in the associated principles and include this deficiency in the mental model. Figure 2 shows the design of the OA/OMIES assessment module.

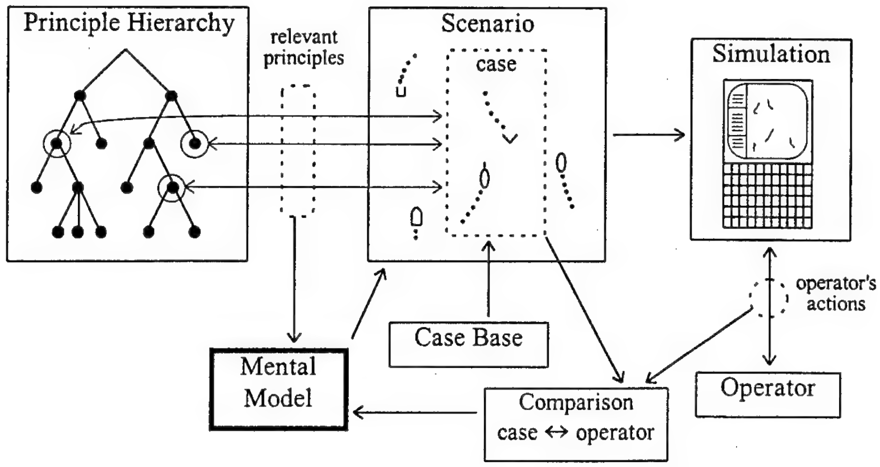

Figure 2. OA/OMIES Assessment Module

Further execution of scenarios allows the OA/OMIES to form an accurate mental model over all domains represented in the principle hierarchy. As the operator continues to be assessed, the system can choose subsequent scenarios containing conditions that focus on certain sets of principles, in order to refine the mental model most efficiently. Because the complete set of principles is hierarchical, the OA/OMIES can also determine that the operator has a broad deficiency in an entire subdomain, mark that branch of the hierarchy as not well known by the operator, and focus on other principles in subsequent assessment. Of course, any operator's mental model can be altered by future assessment sessions.

The OA/OMIES can also identify deficiencies on a higher operational order than specific domain knowledge, such as the inabilities to perform differing kinds of tasks simultaneously, to deal with an overwhelming amount of simultaneous data, and to maintain situational awareness by proper monitoring of different sensor displays. These principles are those in which any operator will have some level of deficiency; that is, thresholds of complexity exist above which even the best operator will be unable to perform effectively. The system will be sensitive to these kinds of deficiencies in addition to those concerning operational knowledge. It is also important to note that some principles might be more appropriately tested in a traditional straightforward test, because their effects on mission simulations are difficult to isolate. Device principles are an example, including knowledge about how to physically operate sensors and the console itself. An operator's understanding of these principles can be tested by the OA/OMIES through a standard test in addition to simulation-based assessment.

Enhancement

The enhancement that the OA/OMIES provides on board the SH-60R is a continuously repeating process consisting of two primary stages: identification and display. The identification stage is similar in nature to the assessment module, in that it consists of determining relevant principles by retrieval of cases similar to the current mission situation. The system has a mental model of the operator available to it, which describes that operator's deficiencies in certain

domains, which will in turn suggest the interface enhancement which will best facilitate the operator at that moment. Determination of the most appropriate enhancement can be expressed as the following process:

(context, principles, deficiencies) => enhancement

Context consists of the current mission situation (e.g., ASW tracking of a particular kind of sub), available sensor data (e.g., known contacts, tracks, speed/heading data), and the activities of the operator (e.g., sensor and console display settings). Context is used differently in each phase of enhancement: generally, in order to retrieve the most similar case and identify the relevant principles on which to act, and specifically, when determining the enhancement to produce. The first sense is general in that a retrieved case is not necessarily identical to the current situation, but is sufficiently similar to identify the relevant principles to be employed in the enhancement process.

Identification

The case-based retrieval facility allows for rapid real-time identification of the most similar case in the case base, which has associated with it a set of relevant operational principles. The principles identified in this fashion are compared to the mental model of the operator, to determine which of them the operator may be lacking. Should a deficiency arise, the OA/OMIES will execute the interface aid associated with the principle in question. In the presence of multiple deficiencies, the system will determine the most appropriate type of aid as a function (function F below) of the principle's criticality, the extent of the operator's deficiency, the immediacy of the context, and the effectiveness of the enhancement in terms of speed and specificity. The identification phase of enhancement can be expressed as the following breakdown of the general process:

$$\text{context}_{\text{general}} \Rightarrow \text{case}$$
$$\text{case} \Rightarrow \text{relevant principles}$$
$$\text{relevant principles, mental model} \Rightarrow \text{relevant aids}$$
$$\text{F(relevant aids, relevant principles, mental model, context}_{\text{general}}) \Rightarrow \text{aid}$$

Display

The aid identified can be of various forms: an alert or help text, a specialized application such as a classification aid, a display alternate to that shown on the operator's console with annotation or declutter, or a display of data from a different sensor altogether. The aid can also have varying content: general help detailing proper equipment operation or relevant tactics, advice consisting of suggested configurations or actions that should (or should not) be taken, information or appropriate conclusions of which the operator might not be aware, or specific facilitation of particular tasks such as a case-based acoustic signature classification aid. Context-insensitive aids are simply shown on the screen; context-sensitive aids, such as suggestions for sonobuoy settings and placement patterns, refers to the current scenario data in order to produce specific advice. As opposed to the identification phase, here the OA/OMIES makes use of

specific quantitative context information, as required by the aid; for example, a buoy placement aid can refer to current tracking data as well as knowledge about the enemy submarine, where a classification aid can draw from real-time acoustic data. The final step of enhancement, then, is the following:

$$\text{aid, context}_{\text{specific}} \Rightarrow \text{enhancement}$$

Sensor Operator's Associate

The physical integration of the OA/OMIES with the SH-60R platform is as an auxiliary display, probably a laptop beside the console on which enhancements, when appropriate, will appear. As an associate entity, the system will be noncritical to the operator's console operation and mission completion, and its failure would incur no detriment to the operator's usual activities. The display will usually be blank, to be unobtrusive and nondistracting to the operator when not needed, and so that the operator does not get used to ignoring it or become dependent upon it for help. With an expert operator, no enhancement may ever be activated. While the OA/OMIES that has been designed is suitable for both ATO and SO, the Phase I prototype will be implemented as an SO's associate, and orient on the tasks that the SO must perform in mission execution.

<u>Other uses of the OA/OMIES</u>

While the OA/OMIES as described could be used directly for specialized just-in-time training, and for post-mission debriefing, the assessment module of the OA/OMIES could easily be built into a full-fledged intelligent tutoring system, with most of the work already having been done. SHAI has extensive experience in case-based, simulation-oriented intelligent tutoring systems, using the approach to assessment described in this design. The case-based approach offers easier and more intuitive alternatives to the difficult and time-consuming processes of knowledge elicitation and training course authoring, and also allows for extensibility of the knowledge base without reimplementation. It is also important to note that the information gathered by the system could also be useful in the interface design process itself. Problems or mistakes that most operators experience might indicate a fault or inefficiency in the interface, and effort can be exerted to correct that problem rather than to train operators in unwieldy tasks.

6.0 Phase I Prototype

The Phase I prototype provides absolute proof of the feasibility of our ideas. It was developed in a two-month time period, from scratch in the Kappa rapid prototyping environment. The Phase I prototype was kept unclassified by not using the correct tactics, though their form is preserved. For demonstration purposes, many of the decisions made by the ATO and SO are combined.

6.1 Functionality

The Phase I prototype implements all phases of the full-scale OM/OMIES, though on a very narrow part of the SH-60R domain. It includes both an assessment module which tests operator knowledge in scenarios running in a tactical simulation, and, an enhancement module. The assessment module assembles an operator model, consisting of what Principles the operator is weak and strong in. The assessment also performs assessment efficiently. That is, if it determines that he knows very little or very much about one part of the SH-60R domain, it marks the entire area accordingly and moves on to scenarios covering other areas.

The enhancement system uses the operator model, in the context of the current situation, to provide the appropriate enhancements. Enhancements included in the Phase I prototype include recreation/improvement of existing sensor displays, knowledge-based advice, advisories, warnings, suggestions, explanations, and domain information (both general and tailored to the context).

6.2 Phase I Design

To a large degree, the design of the Phase I prototype follows the Phase II design given in Section 5.2. That general design is not repeated here, but only the aspects that are particular to the Phase I prototype. Figure 3 shows the high-level contents of the prototype.

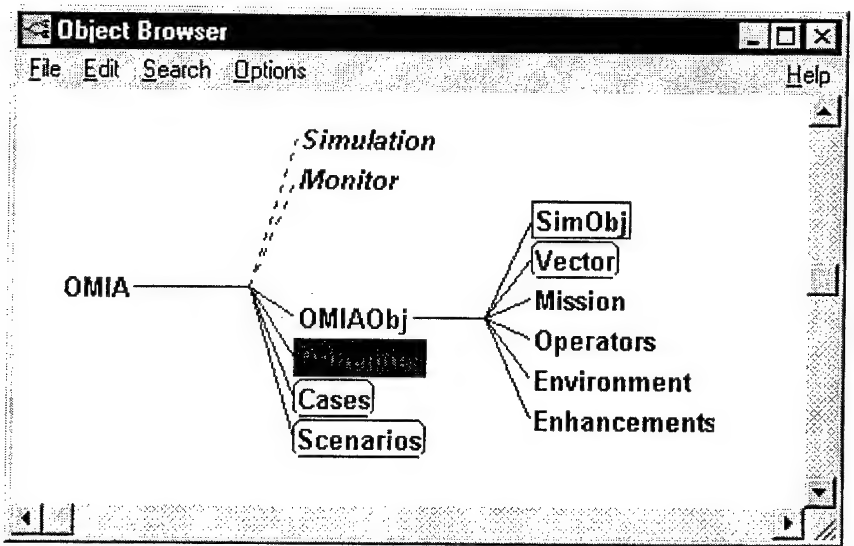

Figure 3. OA/OMIES Prototype

It contains a simulation that supports ASW/ASuW scenarios, a monitor that builds mental models in assessment mode and provides adaptations in enhancement mode, a hierarchy of principles representing the operation knowledge of interest, and set of cases that is used in case-based reasoning to determine the applicability to mission situations, and scenarios in which to carry out assessment and enhancement. Figure 4 shows the operational architecture of the prototype, and is followed by descriptions of the significant components.

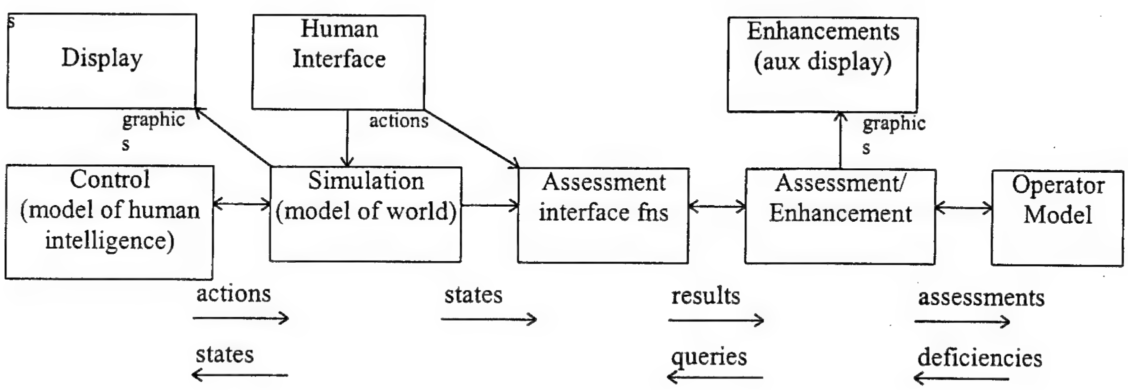

Figure 4. OA/OMIES Prototype Operational Architecture

Phase I Components

1. Simulation
2. Control
3. Human Interface
4. Assessment
5. Enhancement

1. Simulation

The simulation component of the prototype provides the platform for operator assessment and interface enhancement. It plays the roles of both training simulation, in which the system assesses the operator's expertise during simulated missions, and the SH-60R platform itself, in demonstrating some of the interface enhancements that would be made available during a mission. The simulation models the interaction of physical objects in a tactical ASW/ASuW domain, and can include various types of submarines and ships, as well as the SH-60R, weapons available to various platforms, and miscellaneous entities such as decoys. The uppermost portion of Figure 5 shows the set of such objects ('PhysObj's) that are represented.

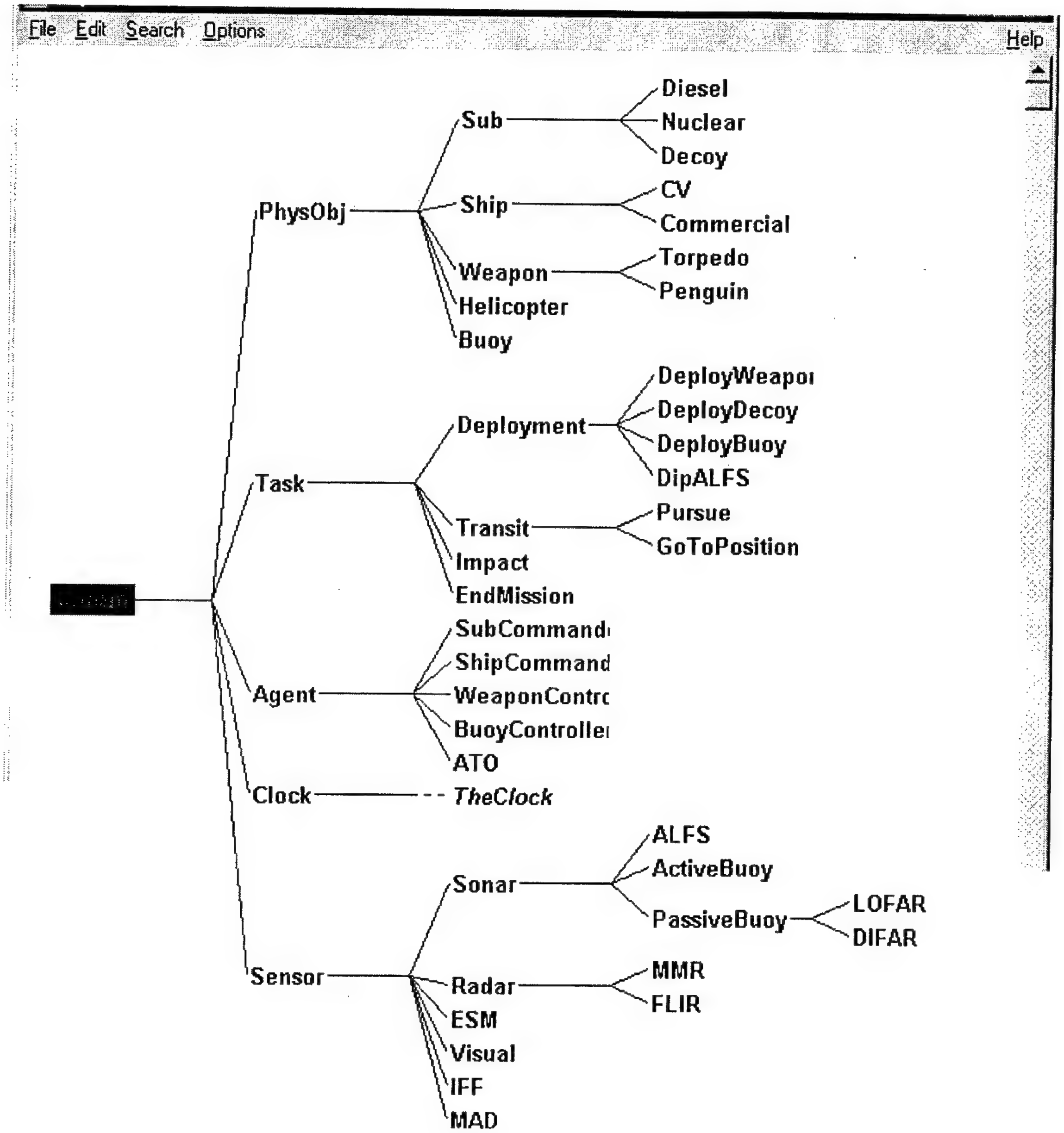

Figure 5. Simulation and Control Entities in the OA/OMIES Prototype

These platforms can have onboard any of the other major set of objects in the simulation, that of sensors. Sensor objects collect data from the simulation and provide that data for use by their platforms. In the scenarios included in this prototype, submarines and ships are equipped only with simple sonar sensors, to allow them the information they need for evasion and attack, while the SH-60R has onboard its full suite of sensors, each of which is constantly generating data and

making it available to the operator while the simulation is running, to produce a simplified replication of an actual ATO station. The set of sensors implemented in this prototype is shown in Figure 5.

2. Control

While the simulation component models the physical environment and the objects in it, updating their states over time, as well as providing data for sensors being used in the simulation, the objects require control entities to perform actions. The OA/OMIES prototype includes an agent architecture that can be used to simulate the commanders of various platforms, which are capable of analyzing the environment via sensor data and performing actions toward the completion of a particular mission. Each scenario included in this prototype specifies a set of ships and submarines that are present, as well as a mission statement for each, which will be used by the agents associated with each object in making decisions while the simulation is being run. The types of agents are shown in Figure 5.

The agents, as well as the human operator using the prototype, manipulate the simulation by assigning tasks to the object with which they are associated. These tasks are shown in Figure 5, and include the deployment of weapons, sensors, or decoys, transit, pursuit, and the like. The SubCommander agent, for example, may notice a contact on the sonar aboard his submarine, and attempt to evade by deploying a decoy and diving below the layer, using the DeployDecoy and GoToPosition tasks.

3. Human Interface

The SH-60R through the same set of possible tasks, but instead of being provided by an agent control entity, these tasks result from the human operator's use of the OA/OMIES interface, shown in Figure 6.

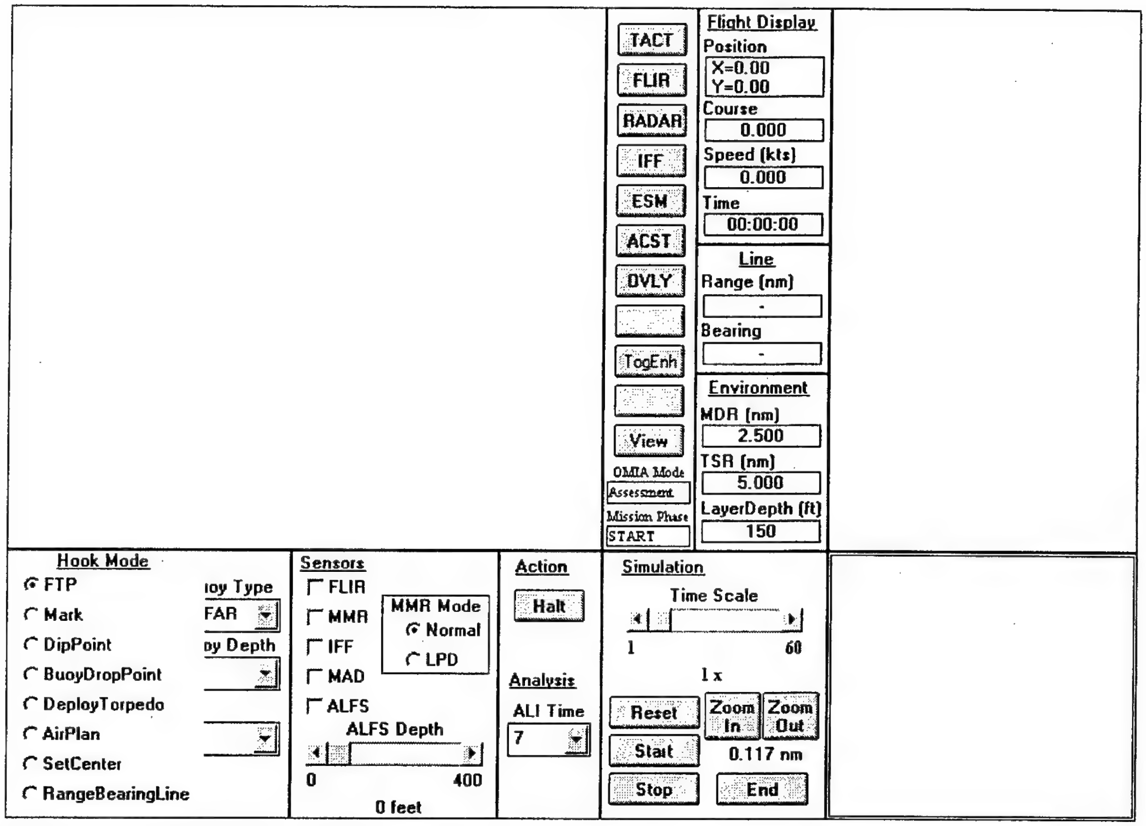

Figure 6. OA/OMIES Operator Interface

The prototype interface represents a simplification of the SH-60R human-machine interface, in addition to some controls to allow the operator to control the helicopter and the simulation itself. The primary display (upper left) shows the sensor data or tactical information corresponding to the display mode selected (upper center, left), including modes for each sensor and for overlays of more than one. Various flight information is also provided (upper center, right). The operator controls the SH-60R via the lower section of windows, which allow the establishment of FTPs, drop points, dip points, weapon deployment points, airplans, and the like, which are executed automatically by the SH-60R 'pilot' (lower left). A panel for the deployment of various sensors is adjacent, as well as a control for the selection of ALI integration time. Various other controls allow stopping, starting, and time compression of the simulation, as well as zooming and centering the primary display. The two rightmost windows shown are reserved for enhancements, as well as messages that annotate the demonstration sequence.

4. *Assessment*

The assessment module of the OA/OMIES prototype follows the design detailed in section 5.2. The principle hierarchy used as a basis for the generation of operator mental models is shown in Figure 7.

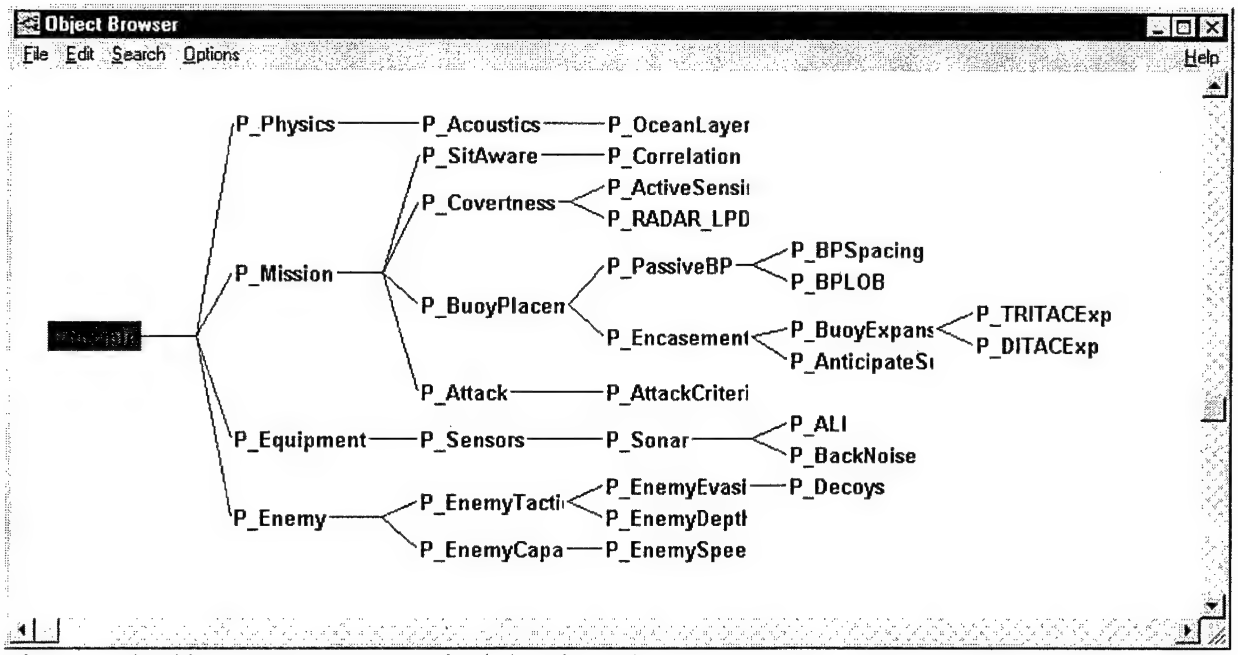

Figure 7. OA/OMIES Prototype Principle Hierarchy

The incomplete and simplified hierarchy used in the demonstration prototype represents, at the highest level, various types of knowledge relevant to the scenarios used in the prototype: physical principles (P_Physics) governing the ocean environment and affecting factors such as the propagation of sound, mission completion principles (P_Mission) including methods for buoy placement and appropriate tactical use of sensors, equipment principles (P_Equipment) of operation for sensors and weapons, and enemy intelligence principles (P_Enemy) of enemy capabilites and of enemy behavior in certain situations. All of the principles associated with the scenarios used in the prototype lie at the bottom level inside these groups. Omitting the intermediary principles, brief descriptions are as follows (note that not every principle is demonstrated explicitly in our demo sequence):

- P_OceanLayer: how the ocean layer affects sound propogation, and how to place hydrophones to exploit/avoid them
- P_Correlation: correlation of contacts on different sensors to improve confidence, classification, etc.
- P_ActiveSensing: the effect of active sensing on covertness
- P_RADAR_LPD: the use of the LPD mode of the MMR for covertness
- P_BPSpacing: the optimal spacing of passive sonobouys in patterns
- P_BPLOB: the appropriate passive sonobuoy pattern to investigate a line of bearing
- P_TRITACExp: TRITAC expansion of split buoys
- P_DITACExp: DITAC expansion of hot buoys

P_AnticipateSub: keeping sensor deployment ahead of expected sub heading
P_AttackCriteria: criteria for attack using various sensor data
P_ALI: appropraite use of ALI time constant for various mission phases
P_BackNoise: the effect of background noise on acoustic sensors
P_Decoys: the characteristics of enemy decoys, and the use thereof
P_EnemyDepth: expected depths of enemy subs, given certain supected intent
P_EnemySpeed: expected speeds of enemy subs, given certain supected intent

5. Enhancement

The enhancements demonstrated by the OA/OMIES prototype are of two basic types: graphic and textual. Each provides a suggestion to the operator, based on the current environmental data and tactical situation, and also provides an explanation of the principle or principles motivating the enhancement. For example, an enhancement that provides a recommended hydrophone depth for a passive sonobouy consults and presents the known ocean layer depth and relevant intelligence about the enemy operating depth, based on platform type and suspected intent.

6.3 Demonstration Sequence Overview

The most important concept of the OA/OMIES is that it adapts itself differently to different operators. To show this capability requires that the demonstration sequence include sub-sequences for two different operators. The first sub-sequence, Operator 1, starts with the Passive Line of Bearing (LOB) scenario. Operator 1 performs very poorly and the system terminates the scenario when it becomes obvious that Operator 1 has a complete lack of knowledge in this area. It then picks another scenario, to test knowledge, not tested in the previous scenario. This scenario is a Passive Datum Assessment scenario. Operator 1 performs most of the actions correctly, showing he is knowledgeable in this area and can apply the relevant tactical principles. Operator 1 is then forced to perform a mission scenario. For demonstration purposes, the simulation plays the role of the actual SH-60R cockpit and environment. During the mission scenario, the Operator receives enhancements appropriate for the principles that the has demonstrated a weakness in.

Operator 2 performs the second sub-sequence. He will make different mistakes than Operator 1, reflecting differing knowledge. This will cause him to get an almost completely different set of enhancements. He starts with the same initial scenario (Passive LOB). He performs much better than Operator 1 and achieves detection (which Operator 1 was never able to accomplish). He the then moves into localization, tracking, and attack. He makes some mistakes but is still able to accomplish a kill. Because he was tested on the principles relating to these tasks, unlike Operator 1, he is able to skip the second assessment scenario. He is then forced to perform the same mission scenario as Operator 1, but receives a very different set of enhancements during this same mission, because the state of his knowledge is so different than A. Much more detail is given on the demonstration sequence in Appendix A, including a large number of screen dumps.

7.0 Future Work

The ultimate goal of this project is a fielded, operational system which performs off-line assessment and on-line OMI enhancment, on-board the SH-60R, for both the ATO and SO positions. This is an emormous scope which must be scaled-back and prioritized for Phase II. In Phase II, we would produce an operational prototype, ready for testing and evaluation, probably interfaced through an RS-232 port to a land-based functional cockpit mock-up. The Phase II system would handle a subset of the applicable knowledge and tasks of the SO or ATO.

The ultimate system, in addition to interfacing to the actual SH-60R avionics must also interface to an SH-60R trainer, for OA/OMIES testing, off-line assessment, and for training the crew in the use of the on-line enhancement.

Future work will include both the development of applicable OMI enhancments by SHAI as well as incorporation of enhancments developed by others. The Decision Support System (DSS) is one example. Our architecture minimizes the difficulty of incorporating enhancments developed by other organizations. SHAI is qualified to develop several different types of enhancments. Which ones we develop, and which ones will be developed by others, must be decided.

The OA/OMIES will useful during mission planning, specifically for mission rehersal. The crew can be put through several scenarios similar to ones that are expected in the course of the real missions. The system can evaluate the crew's responses and determine what elements they are weak in. The relevent enhancments will thus be primed for the real mission, and, for additional "dry runs", if desired.

Another obvious extension to the OA/OMIAS is an Intelligent Tutoring System (ITS). The most difficult aspects of ITSs are generally assement and operator model building. Since these are already being accomplished by the OA/OMAS, only sttraight-forward and minor additions are required to give it an ITS capability. Even simply tying the proinciples back to an electronic version (preferrably multi-media) of the tactical manuals, would go a long way in this direction. Since the OA/OMIES develops lists of poorly applied principles, an ITS could retrieve and present the parts of the tactical manuals specifical relevant ot a particlar operators deficienceis. Another straight-forward addition for ITS use would be the ability to retrieve scenarios for a particular operator based on his particular deficiencies. The could be used as scenario exercises for practice or presented as examples for teaching. Finally, attaching an expert's explanations to the expected operator actions would provide a debriefing capability. When combined with the mission rehersal capability, the ITS provides just-in-time-training.

There are different types of evaluation functions which the OA/OMIES, by its nature, can easily support. The first is operator performance evaluation. The OA/OMIES is assessing the operator in operational scenarios and building a corresponding model of the state of his knowledge. This model can be output in human-readable form and used directly for evaluating the operator's performance of neccessary tasks and his related knowledge. Second, the OA/OMIES can be used to examine how intuitive the OMI is and how effective training is. By

examining the information across different operators, commonalitites can be found. If operators frequently have difficulty with the same aspects, this may indicate either a deficiency in training, or even in the OMI itself.

Finally, during the development of the OA/OMIES, SHAI will be developing the knowledge strucutres for the domain, which could bge used to suport additional purposes. These include ITSs and particular OMI enhancments, especially in the area of ATO and SO Associates.

SHAI *Stottler Henke Associates, Inc.*
1660 S. Amphlett Blvd., Ste. 350
San Mateo, CA 94402
(650) 655-7242
(650) 655-7243 (FAX)
http://www.shai.com

Certification of Technical Data Conformity (May 1987)

The Contractor, Stottler Henke Associates, Inc., hereby certifies that, to the best of its knowledge and belief, the technical data delivered herewith under Contract No. N00421-97-C-1134 is complete, accurate, and complies with all requirements of the contract.

C J Rognier
Signature

CHRIS J. ROGNIER
Name - printed

VICE PRESIDENT - ADMINISTRATION
Title

1/2/98
Date